

The University of Chicago

STUDIES ON RIGOR MORTIS OF THE HEART

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE BIOLOGICAL
SCIENCES IN CANDIDACY FOR THE DEGREE
OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSIOLOGY

1933

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STEPHEN HUNG TE CHANG

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Brouardel, (1) in 1889 for a forensic purpose, reported that the heart passes into a state of rigor after death.

In 1896 Strassmann (2) by comparing the dimensions of the hearts of dogs immediately after death and 24 hours later, showed that during the development of rigor the heart becomes smaller in all dimensions.

Fuchs (3) in 1900 observed that shortly after death fluid injected into the ventricles would pass into the auricles, which showed that the atrio-ventricular valves were patent. About $1\frac{1}{2}$ hours later no liquid could pass from the ventricles into the auricles. He assumed this impassability to be due to the development of rigor. Fuchs further observed that rigor of the heart appears before the occurrence of general rigor, which fact he ascribes to the previous activity of the heart.

MacWilliam (4) in 1901 recorded the development of rigor by cannulating the aortic orifice of isolated cat hearts and connecting the canula with a mercury manometer. He observed that irritability may still persist even after the beginning of rigor.

In 1903, Rothberger (5) studied the nature of the development of rigor in the isolated hearts of 200 dogs. He concluded that filling the heart cavities with physiological salt solution stimulates the cardiac muscle and causes a primary rise in tone. He agrees with Bayliss and Starling (6) that at the time of death there is enough positive intravascular pressure to distend the heart and thus cause soon after death tonic contraction which may pass over into rigor without an intervening primary dilatation.

In 1909, Joseph and Meltzer (7) concluded that the cardiac rigor or tonic contraction, observed by other investigators to set in immediately after death is an artificial phenomenon produced by filling the heart with saline and connecting it with the manometer. They found the stopping of the spontaneous beating, the disappearance of irritability and the development of rigor seen in both ventricles progresses from the base toward the apex. It was also observed that the development of rigor progresses from the endocardial to the epicardial surface.

Hoet and Marks (8) in 1926 observed a rapid onset of rigor mortis in skeletal muscles of animals fed thyroid. They believed it is not due to accumulation of lactic acid nor increased acidity in the muscle tissue.

In 1927 Hans Meltzer (9) confirmed MacWilliam in observing that heart musculature even though already in rigor may still show irritability. He also stated that the left heart usually shows earlier post mortem rigidity than the right, but does not reach the highest point earlier.

Bierfreund (10) in 1888 studied the effect of temperature on the development of rigor mortis in skeletal muscle. Using the hind leg of rabbits he observed that rigor at 4°C. began after $1\frac{1}{2}$ hours, while at a temperature of 35°C. rigor began in 2 to 5 minutes.

In 1927 Morgenstern (11) confirmed and extended the observations of Bierfreund.

For the purpose of studying nutritional effects on cardiac rigor several groups of animals were subjected to dietary modifications. The diets used (Table I) are all modifications of the standard diet. While the standard diet is now known to be somewhat deficient in vitamin B, it did serve to keep the animals in a fairly good state of nutrition for the length of time that the experiments required.

Diet No. 11 is identical with the standard diet except that dietary salts have been replaced by an equivalent quantity of starch. That the salt content might be an important factor in the development of rigor mortis was suggested by the observation of Patras and Templeton (12) in 1932. They showed that restriction of the intake of dietary salts had a beneficial effect in prolonging life and improving the general condition of rats on a vitamin-B deficient diet.

Diet No. 12 is deficient in vitamin B to the extent that definite polyneuritic symptoms develop in rats in from 30 to 50 days. In order to study the influences of dietary salt restriction in vitamin-B deficiency diet No. 13 is prepared identical with diet No. 12 except for a substitution of 3% starch for the salt constituent.

In order to study the influence of thyroid feeding on rigor mortis diets No. 14, 15 and 16 were prepared identical with the standard diet except for the substitution of 0.02%, 0.05% and 0.1% dessicated thyroid for an equivalent quantity of starch.

Previous to the experiment about one-half of the animals were kept on a stock diet supplied by Loyola University, and consisting of Purina Fox Chow, fed daily with the addition of hearts, bread and cabbage once per week. The other half of the animals were kept on a stock diet supplied by the University of

Chicago, consisting of corn meal, powdered skim milk and bread and hearts daily.

Litter mates of the same sex and as near the same weight as practical were divided into groups and kept under comparable conditions except for the desired variations. When the controlled physiological change had been produced, the rats were sacrificed by a blow on the head. Immediately after the death blow the thoracic cavity was opened, the heart removed and suspended in Ringer's solution thermostatically controlled. The apex of the isolated heart was fastened to the end of a bent metal rod which could be lowered into a constant temperature bath. The base of the heart was hooked on a bent pin and connected to a heart lever with a silk string. This process required from 40 to 100 seconds. The activity of the heart was then recorded on a smoked drum. The duration of the different phases in the survival period of the heart was measured in terms of minutes.

Table I.

DIET	CASEIN	STARCH	BUTTER	YEAST	SALT	THYROID
NO. 10 STANDARD	18%	49%	15%	15%	3%	
NO. 11 STANDARD-SALT	18%	52%	15%	15%		
NO. 12 VIT. B DEFICIENT	18%	59%	15%	5%	3%	
NO. 13 V.B.D.-SALT	18%	62%	15%	5%		
NO. 14 0.02% THYROID	18%	48.98%	15%	15%	3%	0.02%
NO. 15 0.05% THYROID	18%	48.95%	15%	15%	3%	0.05%
NO. 16	18%	48.90%	15%	15%	3%	0.10%

In studying cardiac rigor in the isolated heart 3 natural phases are seen. First, the period of activity which is considered as starting with the stunning of the animal and ending when one contraction is followed by at least 1 minute of quiet: Second, the period of quiet which has its beginning with the close of the active period and its end with the beginning of rigor: Third, the period of rigor which begins at the close of the quiet period and ends when no further shortening is measurable. To these natural phases two artificial divisions have been added: latent period of rigor and a speed of completion of rigor, both of which have their beginnings with the stunning of the animal. The division, latent period of rigor, ends with the beginning of rigor. The division, speed of completion of rigor, ends with the completion of rigor.

One hundred and twelve rats were divided into two groups, in one of which there were 55 rats kept on the standard diet and the other 57 rats which received the vitamin-B deficient diet. These animals were sacrificed from 35 to 75 days after the start of the experiment. Some of the animals on the vitamin-B deficient diet emaciated much more rapidly than others. On the basis of emaciation three divisions were made (Fig. 1.). Nineteen rats, (2 in Fig. 1.) emaciated 15% or less, showed that the period of cardiac activity decreased 30% while the period extending from the time the animal was stunned to the completion of rigor was increased about 30%. The quiet period was most affected in vitamin-B deficiency. As emaciation became more profound the period for completion of rigor became more prolonged. This was brought about by an extension of the period of rigor with very little further effect on the quiet period. The period of activity became

shorter as emaciation progressed. Number 3 in Fig 1. represents 24 rats emaciated from 16% to 30%. Number 4 shows 14 rats with a loss of weight ranging from 31% to 45%.

The relation existing between the periods (Table II) is disturbed proportional to the degree of emaciation. The normal relation of 1 to 6 existing between the active period and the period for completion of rigor of the control group is raised to a 1 to 15 proportion in the case of the advanced emaciation. This change in proportion is brought about by an extension of both the quiet and the rigor periods. But the greatest effect is on the period of quiet.

Table II.

The Ratios between the Active Periods and Other Periods.

DIETS	ACTIVE	QUIET	RIGOR	LATENT PERIOD OF RIGOR	SPEED OF COMPLETION OF RIGOR
STANDARD	1	2+	3-	3+	6+
V.B.D.* EMACIATION LESS THAN 15%	1	6+	4-	7+	11
V.B.D. EMACIATION 15% OR MORE	1	6	5-	7	12-
V.B.D. EMACIATION 30% OR MORE	1	8	6+	9	15+

*V.B.D. = vitamin-B deficient diet.

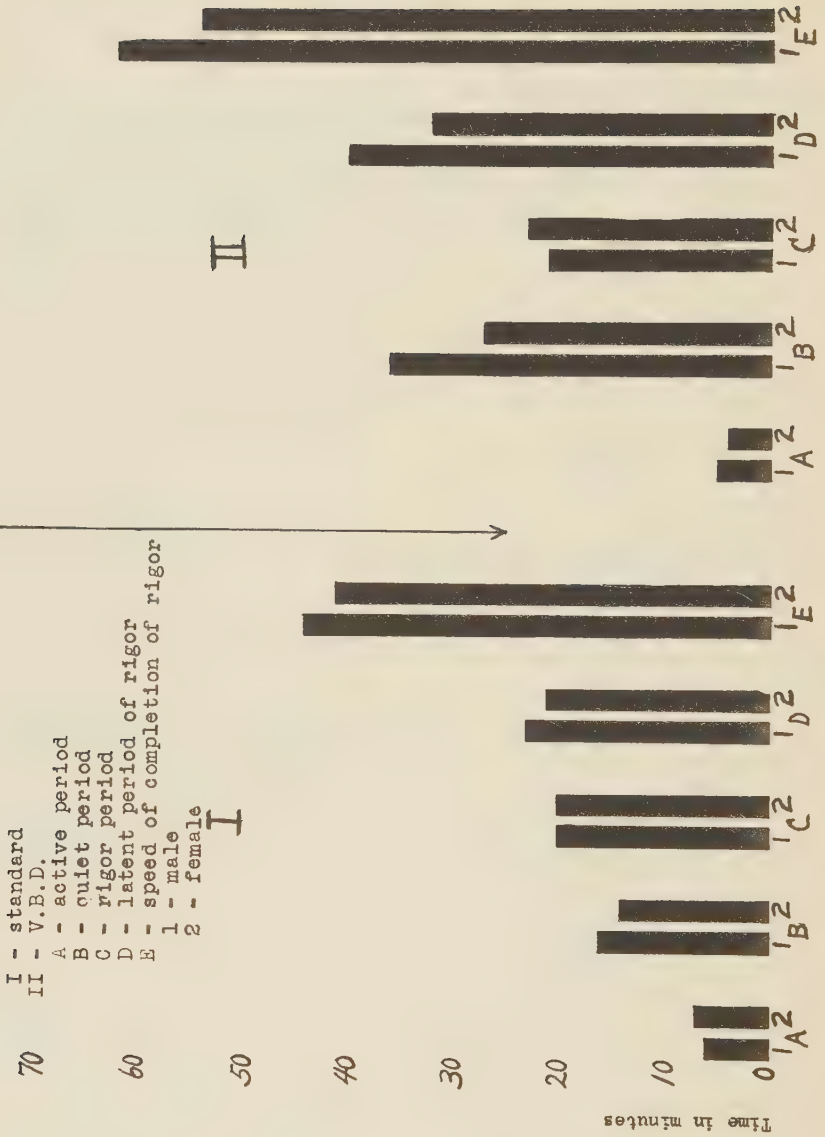
Incidental to the study of vitamin-B deficiency the influence of sex was observed. Of the 55 control animals 28 were males and 27 were females. Fig. 2. number 1. shows the active period to be slightly longer for the females. The period for the speed of completion of rigor for the females is 7% shorter than that of the males. This difference is dependent upon the period

FIG. I

STANDARD AND V.B.D.



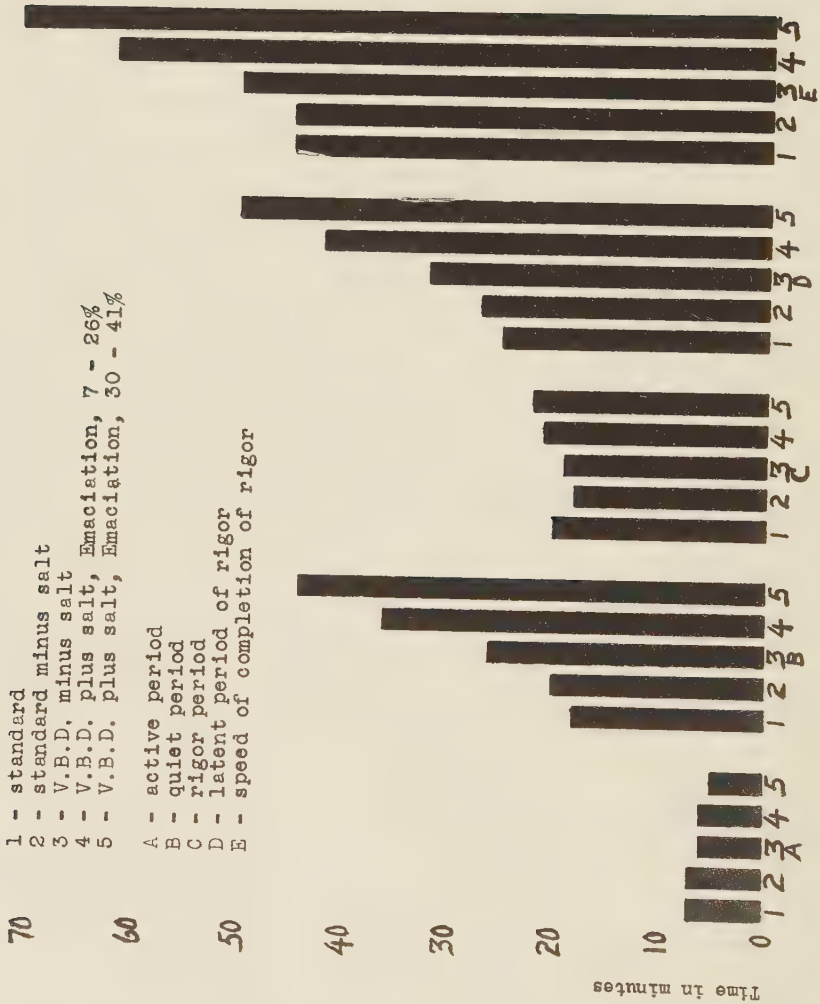
FIG. II



of quiet since the period of rigor is the same for both the males and the females. In Fig. 2. number 3. the difference between the males and females has been plotted for the vitamin-B deficient animals. Here the active period for the males is slightly shorter than that of the females. The period for the speed of completion of rigor is 14% shorter for the females. This difference as in the controls was produced mainly in the quiet period.

Since it has been shown that vitamin-B deficient animals emaciate much less rapidly if their salt intake is restricted (12), 64 rats were divided into four groups for the purpose of studying the influence of salts on rigor mortis of the heart. One group received diet 11, which contained no added salts. A second group received the vitamin-B deficient diet. The third group was fed the vitamin-B deficient diet with restricted dietary salts, while the fourth group was kept for controls on diet 10. In the active period, Fig. 3. number 1. and 2., the simple restriction of salts shows no measurable effect. Although the period of quiet is slightly prolonged by salt restriction, there is a compensatory decrease in the period of rigor, leaving no measurable effect on the period of the speed of completion of rigor. The third group which received the vitamin-B deficient diet to which no salt had been added emaciated less than 20%. The active period is reduced 14% from the controls while the period of the speed of completion of rigor is increased 11% due to the quiet period even though the period of rigor is slightly shorter. For comparison, two divisions were made in the fourth group; those with emaciation less than 30% and those that emaciated more than 30%. The active period of those with emaciation less than 30% is not measurably different from the third group, while those more than 30% emaciation show a decrease in active period 30% below that of the controls and

FIG. III



14% below those on the vitamin-B deficient diet with restricted salt intake. In the quiet period (Fig. 3., B.) the greater the degree of emaciation the more delayed is the onset of rigor. In the period of rigor (Fig. 3., C.) the influence of the loss of weight is not so conspicuous. The net result (Fig. 3., E.) shown in the period of the speed of completion of rigor indicates that vitamin-B deficiency exerts its influence on rigor mortis of the heart proportional to the degree of emaciation.

In Table III the relative proportions between the periods are shown to increase proportionally to the degree of emaciation.

Table III.

The Ratio between the Active Period and Other Periods.

DIETS	ACTIVE	QUIET	RIGOR	LATENT PERIOD OF RIGOR	SPEED OF COMPLETION OF RIGOR
STANDARD	1	2+	3-	3+	6+
STANDARD MINUS SALT	1	3-	2+	4-	6+
V.B.D. MINUS SALT	1	4+	3+	5+	8+
V.B.D PLUS SALT EMACIATION 30% OR LESS	1	6	3+	7	10+
V.B.D. PLUS SALT EMACIATION MORE THAN 30%	1	9-	4+	10-	14

Where only the dietary salts have been restricted the relation of the periods to one another is practically not changed, but in the case of advanced emaciation in vitamin-B deficiency the relation between the active period and the period through rigor is raised from a normal of 1 to 6 ratio to that of 1 to 14.

In order to determine if loss of weight was the controlling factor producing the difference between the vitamin-B deficient plus salt and the vitamin-B deficient diet minus salt, 26 animals were divided into two groups; one-half received diet 12 (the vitamin-B deficient diet) while their litter-mates received diet 13(vitamin-B deficient diet minus salt). In the previous experiment it was found to be impossible in the same number of days to produce comparable degrees of emaciation. An arbitrary limit of the quantity of loss of body weight by the animals receiving salt before sacrifice was set at 30%. To this level it was hoped to emaciate those animals restricted in their salt intake. Of the 26 animals, however, on restricted salt intake only 6 could be caused to lose this quantity of weight even though some of the animals were kept on the diet 30 days longer than those receiving salts. For study we have divided the salt-restricted animals into two groups, those emaciated less than 30% and those emaciated more than 30% (Fig. 4.) Here it is shown that the period of quiet is practically unchanged for the three groups; the most emaciated salt restricted animals showed only a slightly longer period. In the period of the speed of completion of rigor, the vitamin-B deficient minus salt animals with a loss in weight less than 30% is 56% shorter than those emaciated more than 30% and 54% shorter than the animals receiving the dietary salts. Practically this same difference is seen in both the periods of quiet and the period of rigor. Again it is suggested that the increased time required for the heart of vitamin-B deficient animals to reach the completion of rigor may be related to the degree of emaciation obtained.

In order to further study the effect of emaciation 14 rats that had been on the standard diet 30 days were subjected from

FIG. IV



3 to 6 days of starvation before sacrifice. In this time the animals lost 7 to 47% of their body weight. Fig. 5., 3 and 4 shows the male and female starvation animals compared with their litter-mate controls. The active period for the females is slightly longer than that of the males in the control group and 50% longer in the starved group. In the period of the speed of completion of rigor the males required 24% more time than the females in the case of the controls, and 4% more time in the starved group. Both the period of quiet and the period of rigor contribute to this difference.

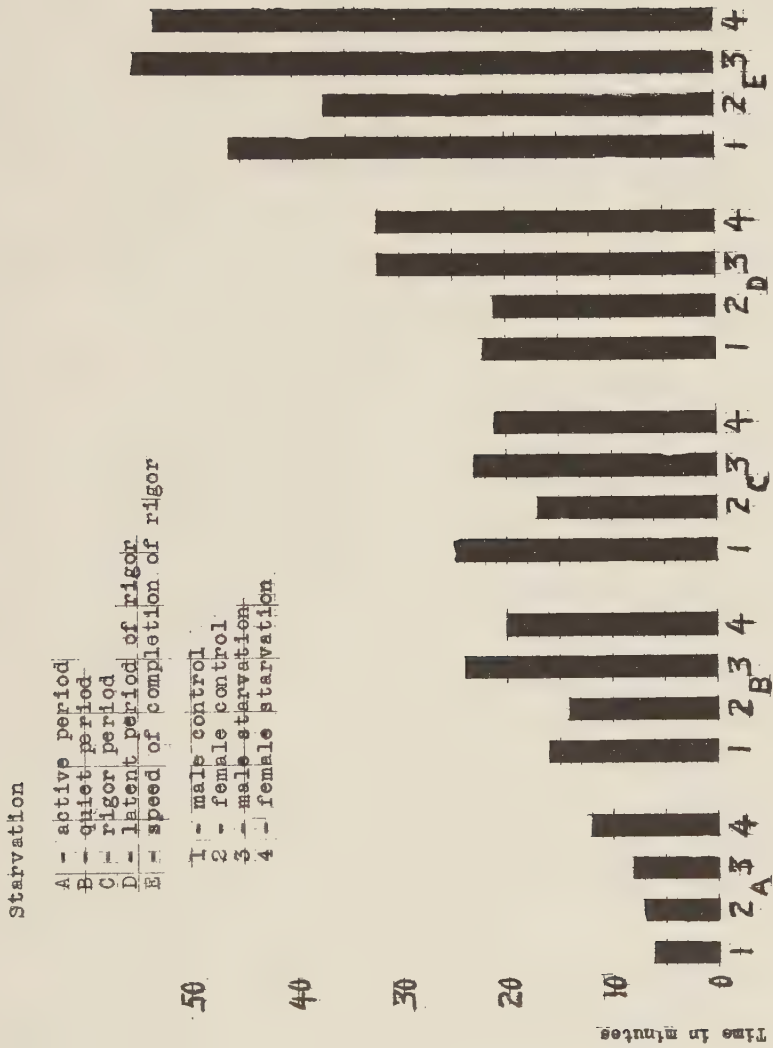
In this figure it is clearly shown that starvation delays the completion of rigor in both males and females by its effect on the periods of quiet and of speed of completion of rigor. This effect is similar with that produced in vitamin-B deficiency. It must be noticed, however, that the period of cardiac activity is increased by starvation which is just the opposite to the effect of vitamin-B deficiency. This experiment, of course, considers only acute starvation. It is possible that if the animals were slowly starved by simply restricting the food intake to a time comparable to the vitamin-B deficient experiments, the active periods might be effected in the same direction.

Table IV.

The Ratios between the Active Period and Other Periods

DIETS	ACTIVE	QUIET	RIGOR	LATENT PERIOD OF RIGOR	SPEED OF COMPLETION OF RIGOR
STANDARD	1	2+	3+	3+	7
STARVATION	1	2+	2+	3+	6

FIG. V



In Table IV the relative proportion between the periods is seen to be practically undisturbed.

Other methods of emaciating the animals might now be considered, among these, thyroid feeding. The effect of thyroid feeding on a contraction of the heart and rigor mortis of skeletal muscle has been studied but its effect on cardiac rigor has not been determined. For the study of the influence of thyroid 88 rats were divided into four groups each containing litter-mate representatives. One group received the standard diet. A second was fed diet containing 0.02% thyroid. The third group received 0.05% thyroid and the fourth 0.1%. The animals were sacrificed after 21 to 61 days on their respective diets.

Animals receiving 0.02% thyroid for only twenty-one days show an onset of cardiac rigor after death practically the same as the controls, after forty days; however, all of the periods except the period of quiet, preceeding the completion of rigor are shortened. The influence of 0.05% of thyroid in the diet can be seen to have an earlier and more profound effect in shortening of all the periods studied. The effect of 0.1% thyroid is exerted to a measurable extent in 21 days and becomes more profound as the duration of the experiment extended.

Fig. 6 shows that an increase in the quantity of thyroid fed causes a decrease in the active period and the period of the speed of completion of rigor. The shortening is due mainly to the shorter active and quiet periods, the effect on the speed of completion of rigor being less marked.

Table V shows that thyroid feeding has very little effect on the relative proportion existing between the periods.

For the purpose of securing a curve to which the various effects studied might be referred, the influence of temperature

FIG. VI

Thyroid

- A - active period
 - B - quiet period
 - C - rigor period
 - D - latent period of rigor
 - E - speed of completion of rigor
- 1 - controls
 - 2 - diet with 0.02% thyroïd
 - 3 - diet with 0.05% thyroïd
 - 4 - diet with 0.1% thyroïd

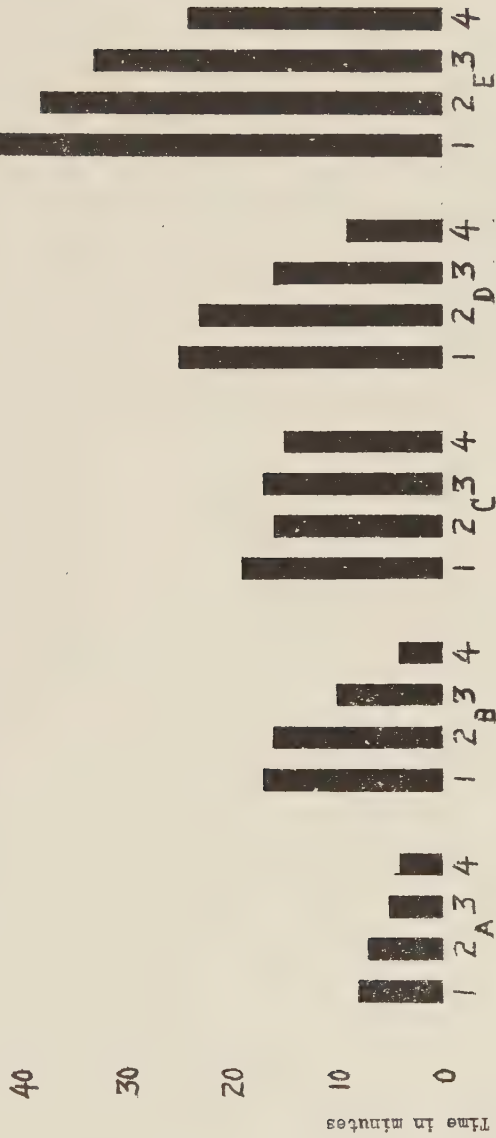


Table V

The Ratio between the Active Periods and Other Periods of the Thyroid Treated Hearts.

DIETS	ACTIVE	QUIET	RIGOR	LATENT PERIOD OF RIGOR	SPEED OF COMPLETION OF RIGOR
THYROID CONTROLS	1	2	2+	3	5+
THYROID 0.02%	1	2+	2+	3	5+
THYROID 0.05%	1	2-	3-	3-	5+
THYROID 0.10%	1	1	4-	2	6

on cardiac rigor was determined upon 71 rats that had been kept on the standard diet for about 60 days. The range of temperature studied varied from 20° to 40°C. Since it was impossible to obtain litters large enough to have one litter-mate representative at each temperature studied, the animals were distributed in such a way as to have litter-mates overlapping at as many points as possible. In addition the hearts of 55 rats, kept on the standard diet from 35 to 75 days, were isolated and studied at 30°C. Since this temperature was used in all the experimental work it was considered most important to accurately establish this point.

Changes in temperature did not materially change the relative proportion between the phases. The proportion between the period of activity and the period of quiet and of rigor being 1 to 2 or 3 at practically all the temperatures studied (Table VI.) In general the active period became progressively shorter as the temperature was increased, proportionally, however, the other periods were also decreased. Although there was more irregularity between the temperatures of 26° to 32°C., it carried a compensatory element in that where the quiet period was short the period of

Table VI

The Ratio between the Active Periods and Other Periods at Different Temperatures

TEMPERATURE	ACTIVE	QUIET	RIGOR	LATENT PERIOD OF RIGOR	SPEED OF COMPLETION OF RIGOR
20	1	3+	2+	4+	6+
24	1	2+	2-	4-	5+
26	1	2+	1+	3+	5-
28	1	3-	2+	4-	6
29	1	3	2+	4	6+
30	1	2+	3-	3+	6
31	1	3-	2-	4-	5+
32	1	2+	3+	3+	6+
34	1	4	3	5	8
36	1	3	3	4	7
38	1	2	4	3	7
40	1	2+	3	3+	6+

rigor was slow. A curve, therefore, representing the two phases (quiet and rigor) is fairly smooth and shows the combined period to become proportionally shortened as the temperature is increased. The artificial period of the speed of completion of rigor which measures the total time from the stunning of the animal to the completion of rigor (Fig. 7.) gives a fairly smooth curve to which other conditions may be referred. At 20° the rigor was not complete until 103 minutes after the animal was stunned, while at 40° the completion of rigor occurred in 19 minutes.

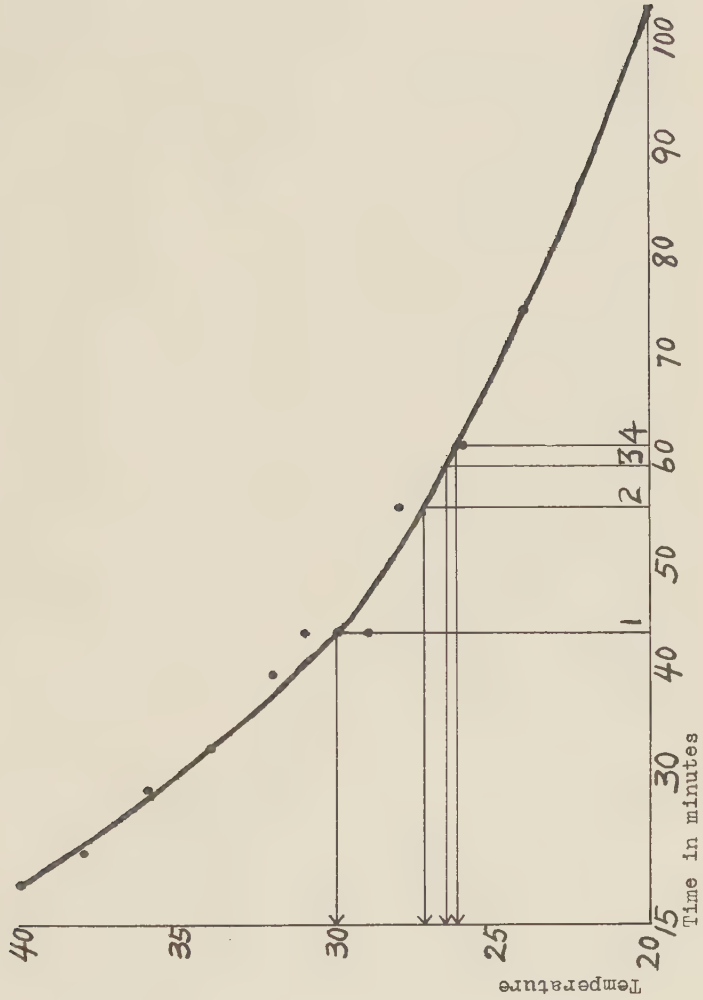
Figure 8., 1. shows the influence of vitamin-B deficiency on the time required for the completion of cardiac rigor. All hearts were kept at a temperature of 30°C. The control animals

FIG. VII



FIG. VIII

- 1 - standard
- 2 - V.B.D., Emaciation, 15% or less
- 3 - V.B.D., Emaciation, 16 - 30%
- 4 - V.B.D., Emaciation, 31 - 45%



showed rigor complete in 43 minutes. The vitamin-B deficient animals emaciated 15% or less (Fig. 8., 2.) showed rigor complete in 55 minutes which when plotted on the temperature curve indicates this degree of V.B.D. to be equivalent to lowering the temperature on a normal heart by approximately 3°C. As emaciation progressed the completion of rigor was delayed so that in those animals emaciated more than 30% (Fig. 8., 2.) rigor was complete in 61 minutes which is equivalent to lowering the temperature by approximately 4°C. on normal hearts.

The influence of salt restriction on the completion of rigor is shown in Fig. 9. Here number 1 represents the control animals for this group. The completion of rigor for these animals was slightly longer than that for the animals used to establish the temperature curve. According to the plot these control hearts went into complete rigor at a time comparable to lowering the temperature by $\frac{1}{2}$ °C. Number 1 also represents the standard animals which had received no dietary salts. The vitamin-B deficient animals which received no dietary salts are represented by number 2 showing rigor complete in 50 minutes, which would be equivalent to lowering the temperature of their controls by approximately 1 minute.

Number 3 represents vitamin-B deficient animals that received dietary salts and were emaciated 30% or less. Number 4 represents those that lost more than 30% and shows the completion of rigor prolonged to 7 minutes, which is equivalent to lowering the temperature on their controls 5°C.

The effect of starvation on the completion of rigor is shown in Fig. 10. The controls represented by number 1 are practically the same as the standards used to determine the temperature curve. Number 2 shows that starvation prolonged

FIG. IX

- 1 - standard and standard minus salt
- 2 - V.B.D.minus salt
- 3 - V.B.D.plus salt, Emaciation less than 30%
- 4 - V.B.D.plus salt, Emaciation more than 30%

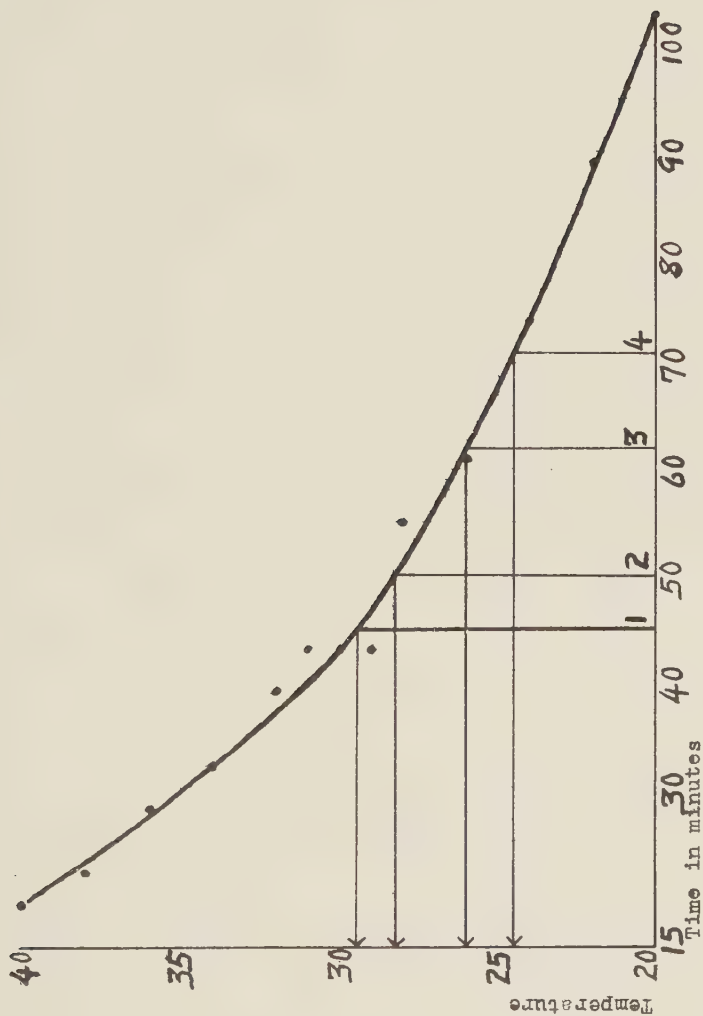
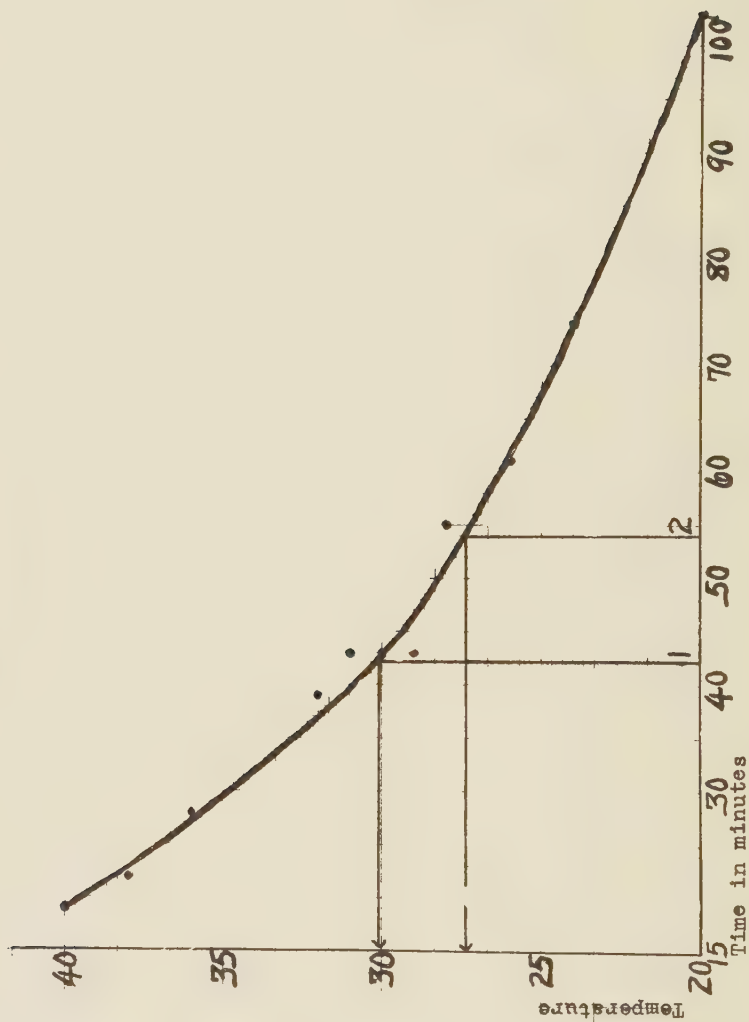


FIG. X

1 - controls
2 - starvation



the completion or rigor to 54 minutes which is equivalent to lowering the temperature on their controls approximately 3°C.

Fig. 11. shows the influence of feeding thyroid on the completion of rigor. Number 1, the standard for this group, went into rigor 1 minute later than the animals used to establish the temperature curve. Number 2 shows the influence of feeding 0.02% thyroid; rigor was complete in 38 minutes which is equivalent to raising the temperature on their controls by 2°C. Increasing the quantity of thyroid ingested to 0.05% and 0.1% has the effect shown at numbers 3 and 4 respectively. It takes 0.05% to raise the temperature of the control rats 4°C. while feeding 0.1% thyroid is equivalent to raising the temperature by 7½°C.

The active period of the hearts in vitamin-B deficiency and in the thyroid-fed animals is decreased in a similar proportion (Table 7). The longer the animal has been fed thyroid or the more emaciated he has been rendered by vitamin-B deficiency, the shorter is the active period. The influence of dietary salts is shown to have very little disturbing effect on the relative proportion between the periods. In Table 7., D. the quiet period is shown to be raised from a 1:1 ratio by starvation to a 1:1.5 relation.

In both the quiet and the rigor periods the ratio between the controls and the vitamin-B deficiency is disturbed proportionally to the degree of loss of weight (Table 7.). In advanced emaciation a 1:2 ratio is established in the quiet period while in the period of rigor a ratio of 1:1.2 may be reached. The influence of dietary salts is most noticeable in vitamin-B deficiency where its absence is beneficial in retarding emaciation.

FIG. XI

Thyroid

- 1 - control,
- 2 - 0.02% thyroid
- 3 - 0.05% thyroid
- 4 - 0.1% thyroid

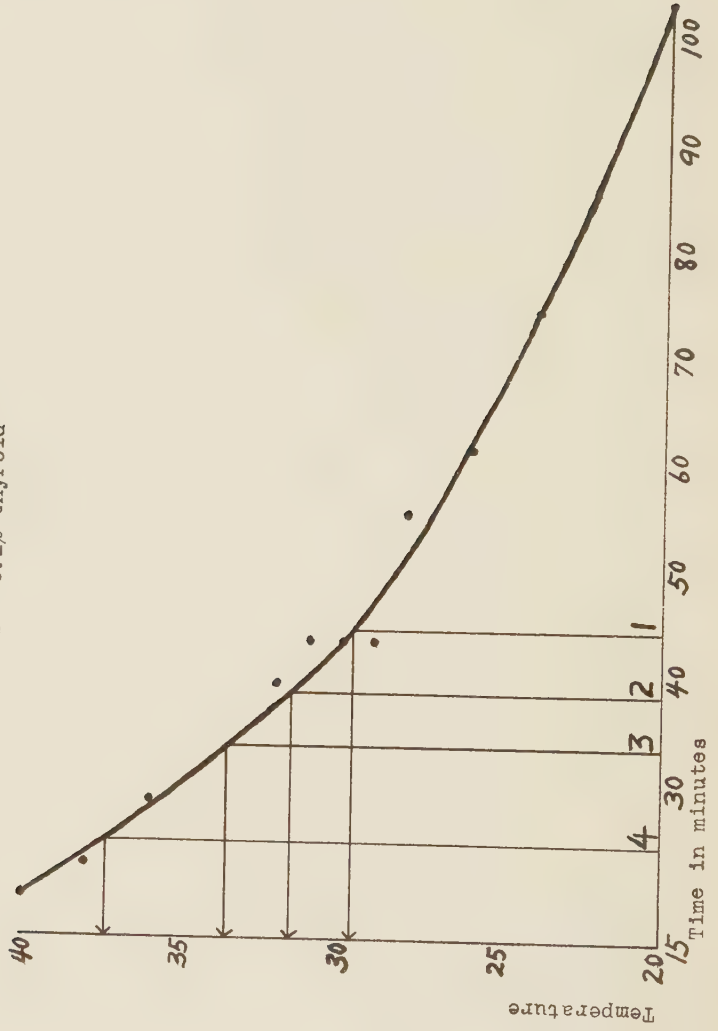


Table VII
Ratios between All the Periods of the Control Animals and Periods of Animals in Different Experimental Conditions

A.				B.		C.		D.	
V.B.D.				THYROID FEEDING		STARVATION		V.B.D. + t - s.	
PERIOD CONTROL	30% EMACIATED	>15% EMACIATED	<15% EMACIATED	CONTROL	.02% .05% 0.1%	CONTROL	STARVATION	CONTROL - s.	V.B.D. + s. EMACIATED <30% >30%
ACTIVE	1 0.6-	0.7+	0.7+	1	0.8+ 0.8-0.5	1	1.5	1 0.9-	0.9- 0.7
QUIET	1 2.1+	2.0	2.1+	1	0.9+ 0.6-0.2+	1	1.4-	1 1.1+	2.0 2.4+
RIGOR	1 1.2+	1.2-	0.9	1	0.8+ 0.9-0.8-	1	1.0+	1 0.9	1.1- 1.1
LATENT PERIOD OF RIGOR	1 1.6+	1.5+	1.7-	1	0.9+ 0.6+0.4-	1	1.5+	1 1.0+	1.7- 2.0
SPEED OF COMPLETION OF RIGOR	1 1.4+	1.4-	1.3-	1	0.9- 0.8 0.5+	1	1.3-	1 1.1+	1.3+ 1.6-

In starvation the relative proportions between the controls and those on starvation (Table 7., C.) in the periods of quiet and rigor is disturbed similarly to vitamin-B deficiency.

An opposite effect is observed in the case of thyroid-fed animals. In the quiet period (Table 7., B.) the ratio may reach 1:0.2 between the controls and those receiving 0.1% thyroid. The rigor period while not disturbed to the same degree shows a similar effect.

It has been shown that the effect of vitamin-B deficiency on the process of cardiac rigor is proportional to the degree of emaciation of the animal. In the present experiments these effects were equivalent to raising the temperature of the isolated heart in proportion to the duration and quantity of thyroid fed. The influence of dietary salts seems to have no effect on cardiac rigor except as it influences the degree of emaciation of the animals.

SUMMARY.

1. Vitamin-B deficiency shortens the active period and retards the completion of rigor mortis of the isolated heart. It is suggested that this effect is due to emaciation.

2. While acute starvation has practically the same effect on the time for the completion of rigor as vitamin-B deficiency, an opposite effect is seen on the active period.

3. Thyroid-feeding accelerates the onset and development of cardiac rigor proportionally to the dosage and duration of feeding. The period of cardiac activity is also decreased in thyroid-fed animals.

4. An attempt has been made to express in temperature equivalents the extent to which the period of the speed of completion of rigor is effected.

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